

秸秆深还对土壤团聚体中胡敏素结构特征的影响^{*}

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摘 要 秸秆还田主要是覆盖和表层浅施, 存在着影响种子发芽生长、土壤升温慢和病虫害增加等问题。秸秆深还 (Deep application of straw, DAS) 是指将玉米秸秆施入土壤亚表层 (20~40 cm), 不仅能解决秸秆焚烧的问题, 还能达到保碳、蓄水、培肥、稳产的目的, 使秸秆还田得到改善。虽对秸秆深还后胡敏素 (Hu) 的结构性质有一些研究, 但是对秸秆深还后土壤团聚体中 Hu 的变化还未见报道。探究秸秆深还对土壤腐殖质的影响, 可以为如何提高土地肥力、如何利用秸秆深还创建合理耕层提供理论依据。本试验采集于吉林农业大学试验站玉米连作耕地试验田, 采用湿筛法将其分为 >2 mm、2~0.25 mm、0.25~0.053 mm 和 <0.053 mm 4 个粒级并提取 Hu, 通过元素组成、红外光谱和差热分析研究秸秆深还对团聚体中 Hu 结构特征的影响。结果表明: 用此方法制备的黑土 Hu 的平均含碳量为 721 g kg⁻¹; H/C 的平均值为 0.776; Hu 的缩合度高于相应的 HA; 秸秆深还促使土壤表层和亚表层团聚体中 Hu 的氧化度降低, 脂族链烃减少, 活性结构增多, 稳定性降低, Hu 的结构趋于简单化、年轻化。

关键词 秸秆深还; 土壤团聚体; 胡敏素; 元素组成; 红外光谱; 差热分析

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我国秸秆资源数量巨大, 但目前并没有得到充分有效利用。秸秆还田是秸秆利用的主要方式之一, 但目前的覆盖或表层浅施也存在一些问题, 或土壤升温慢、病虫害增加; 或使土壤大孔隙过多导致“跑风”, 影响种子发芽, 农民处理秸秆多采用直接焚烧或田间地头无序堆放, 不仅造成环境污染, 也给耕作带来诸多困扰。并且, 覆盖或表层浅施对土壤有机质 (尤其是腐殖质) 的积累作用不明显, 不利于解决耕层变浅、亚表层有机质亏缺等问题。“秸秆深还” (Deep application of straw, DAS) 指将玉米秸秆通过机械化手段施入土壤亚表层 (Subsoil layer, SL, 20~40 cm), 从以往的表层培肥延伸到亚表层培肥, 既可以提高深翻的效率, 又不影响正常种地, 同时有利于长期处于“饥

饿”状态的亚表层积累有机质。解决了目前土壤耕层变薄, 犁底层变浅、变厚、变硬, 缺少有机质、蓄水能力下降等问题, 又减少了由于焚烧秸秆造成的环境污染, 达到保碳、蓄水、培肥、稳产的目的, 是传统秸秆还田的创新和优化。

过去对传统秸秆还田的研究较多, 例如秸秆还田能增加全氮、碱解氮、有效磷、速效钾和水稳性团聚体的含量^[1-6], 有助于腐殖质积累^[7]和 Hu 形成^[8-9]; 提高土壤保水性能^[10]; 改善微生物生存环境^[11]和提高土壤酶活性^[12]。但也有学者认为秸秆还田存在着病虫害增多、影响种子发芽、与作物争抢氮元素等问题^[13], 同时温室效应大幅增加, 是一项重要的温室气体泄漏^[14-15]。而关于秸秆深还的研究较少, 仅有的几篇报道表

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明, 秸秆深还有利于土壤有机质含量和微团聚体的团聚度提高, pH降低^[17]; 促使土壤有益微生物数量和土壤酶活性显著提高^[18], 有利于入渗速率和保水保肥能力提高^[19-20]; 其温室气体的排放量适中^[21]; 胡敏酸(HA)的缩合度、芳香结构和热稳定性增加, 分子结构变复杂^[22]; Hu的芳香结构减少或缩合程度降低^[23]。关于Hu的结构特征有一些报道, Hu较HA腐殖化程度、脂化度和疏水度高, 而极性弱^[24]; 长期不施肥土壤<0.053 mm粒级团聚体中铁结合胡敏素(HMi)的分子质量大, 缩合度高, 结构复杂^[25]; 化肥促使Hu含量增加, 有机肥化肥配施促使Hu缩合度降低^[26]; 微生物促使Hu芳香性降低, 氧化度升高^[27]; 随着堆肥时间的延长, 堆料中总有机碳和Hu含量降低, Hu对五氯苯酚(PCP)的吸附能力逐渐降低^[28]。

虽对不同施肥条件下Hu的结构性质有一些研究, 但是对秸秆深还后Hu变化的研究较少, 对秸秆深还后团聚体中Hu结构特征的变化几乎没有报道。本文采用湿筛法制备土壤表层和亚表层团聚体并提取胡敏素(Hu), 通过元素组成、红外光谱和差热分析研究秸秆深还对团聚体中Hu结构特征

的影响, 为如何提高土地肥力、如何利用秸秆深还创建合理耕层提供理论依据。

1 材料与方法

1.1 研究区概况

试验田选自吉林农业大学试验站玉米连作耕地(N43° 48' 43.57", E125° 23' 38.50")。位于吉林省长春市净月区, 属于北温带大陆性季风气候, 土壤类型为半湿温半淋溶土亚纲黑土类, 相当于美国系统分类的粘淀湿润软土(Argiudolls), 具体相关信息见前文^[29]。

1.2 试验设计

供试土壤采自试验田的未秸秆深还(CK)和秸秆深还(DAS)处理。CK不挖沟, 不施用秸秆; DAS处理在2011年11月进行秸秆深还, 还田量12 000 kg hm⁻², 一次性全量还田, 并配施化肥(尿素450 kg hm⁻²), 具体深还措施见前文^[29], CK与DAS进行同样的耕作。于2012年10月采表层(0~20 cm)和亚表层(20~40 cm)的土壤。供试土壤基本性质见表1。供试土壤的团聚体组成和有机碳含量见表2。

表1 供试土壤的基本性质^[29]

Table 1 Basic properties of the soil tested in the experiment							
土壤类型 Soil type	采集深度 Depth (cm)	有机质 Organic matter (g kg ⁻¹)	全氮 Total N (g kg ⁻¹)	碱解氮 Alkalytic N (mg kg ⁻¹)	有效磷 Available P (mg kg ⁻¹)	速效钾 Readily available K (mg kg ⁻¹)	pH
黑土	0~20	20.51	1.02	77.70	11.52	74.46	7.71
Black soil	20~40	19.28	1.45	84.23	11.66	67.87	7.77

表2 供试土壤团聚体的组成和有机碳含量^[29]

Table 2 Composition and organic carbon content of the soil aggregates tested in the experiment				
土壤类型 Soil type	采集深度 Depth (cm)	粒级 Fraction of particle size (mm)	团聚体相对含量 Aggregate relative content (%)	有机碳含量 Organic carbon contents (g kg ⁻¹)
黑土 Black soil	0~20	>2	17.51	15.04
		2~0.25	40.40	13.68
		0.25~0.053	20.94	12.84
		<0.053	18.59	11.83
		>2	7.294	14.60
	20~40	2~0.25	47.33	12.54
		0.25~0.053	21.97	13.21
		<0.053	20.95	12.07

1.3 项目分析与测定

1.3.1 团聚体分组 采用Cambardella和Elliott^[30]的湿筛法对团聚体进行物理分组, 具体操作为: 称取风干土样100 g, 将孔径分别为2 mm、0.25 mm和0.053 mm的套筛按顺序由上到下组合好, 将称量好的土样均匀铺洒在最上层, 套筛放置于盛有蒸馏水的水桶内, 调整桶内水面高度, 在室温条件下浸润5 min后, 以速度为30次 min^{-1} 和上下振幅为3 cm振荡2 min。筛分结束后, 将每层筛上的团聚体冲洗至烧杯中, 获得 >2 mm、 $2\sim0.25$ mm和 $0.25\sim0.053$ mm的水稳性团聚体, <0.053 mm团聚体在桶内沉降48 h, 弃去上清液后转移至烧杯中。将烧杯中的团聚体烘干称重, 计算各粒级团聚体的百分含量, 同时将烘干的团聚体磨细过0.25 mm筛, 备用。

1.3.2 Hu的提取与结构性质的测定 称取过0.25 mm的风干土样10 g于100 ml离心管中, 加80 ml蒸馏水提取24 h离心后弃去上清液, 上述方法进行2次。向离心管中加入80 ml的 0.1 mol L^{-1} NaOH溶液, 24 h后离心得到腐殖质(HE, 可用于提取FA和HA), 重复此方法直至提取液颜色很浅为止。离心管中的残渣依次用体积比为0.5%、2.5%、5%、10%、20%、30%和40%的HCl—HF混合液分别处理7、7、11、6、4、2和1次, 每次间隔12 h。如以上步骤后感觉还有沙粒没有洗净, 可适当用20%的混合酸再洗几次, 最后用蒸馏水洗至无 Cl^{-} 反应(AgNO_3 检验), 再经冷冻干燥, 得到纯Hu^[31]。Hu碳含量及元素组成采用Elementar Vario EL III型元素分析仪在C\H\N模式下进行测定, 其中Hu的C、H、N元素含量为实测值, O和S元素含量的总和采用差减法计算获得; Hu的红外光谱在AVATAR 360傅立叶变换红外光谱仪上测定, 采用KBr压片法(Hu和KBr的重量比例约为1:250), 测试范围为 $4000\sim500\text{ cm}^{-1}$, 扫描次数128次, 分辨率 8 cm^{-1} , 采用仪器自带的分析软件对红外谱图进行半定量分析, 用每一峰面积的百分比相对地比较峰强度; 差热分析运用Shimadzu TG-60热重分析仪进行测定, 称取样品量为3~10 mg, 在 200 ml min^{-1} 的空气流量条件下, 以 $5\text{ }^{\circ}\text{C min}^{-1}$ 的升温速度由 $25\text{ }^{\circ}\text{C}$ 升至 $110\text{ }^{\circ}\text{C}$, 保持60 min以确保水分全部蒸发, 之后继续以 $5\text{ }^{\circ}\text{C min}^{-1}$ 的升温速度由 $110\text{ }^{\circ}\text{C}$ 升至 $600\text{ }^{\circ}\text{C}$, 保持30 min, 用 $\alpha\text{-Al}_2\text{O}_3$ 做参比进行校正, 并通过计算机测量峰面积, 计算反应

热, 进行半定量分析。

1.4 数据处理

文中数据采用Microsoft Office Excel 2007软件进行数据处理, 红外光谱和差热分析用Origin7.5软件分析作图。

2 结果与讨论

2.1 秸秆深还对土壤团聚体中Hu元素组成的影响

腐殖质主要由C、H、O、N、S等元素组成, 其主体是由羧基—COOH和羟基—OH取代的芳香族结构, 烷烃、脂肪酸、碳水化合物和含氮化合物结合于芳香结构上。腐殖质中H/C和 $(\text{O}+\text{S})/\text{C}$ 摩尔比能够用来表征Hu缩合度和氧化度的强弱^[32], H/C比值与Hu的缩合度呈反比, $(\text{O}+\text{S})/\text{C}$ 比值与Hu的氧化度呈正比。

前文^[29]中CK处理表层和亚表层的平均有机碳含量为 13.2 g kg^{-1} , DAS处理为 14.2 g kg^{-1} , 上升幅度为7.19%; 表层由 13.4 g kg^{-1} 上升至 14.1 g kg^{-1} , 变化幅度为5.39%, 亚表层由 13.1 g kg^{-1} 上升至 14.3 g kg^{-1} , 变化幅度为8.98%, 显然亚表层上升的幅度较大, 这是由于秸秆深还直接深入亚表层, 使“饥饿”的土壤充分与秸秆接触, 有利于腐殖质形成和土壤固碳。亚表层中4个粒级有机碳含量的变化也明显不同: >0.25 mm粒级, 由 13.6 g kg^{-1} 上升至 16.4 g kg^{-1} , 变化幅度为18.6%; <0.25 mm粒级由 12.6 g kg^{-1} 下降至 12.3 g kg^{-1} , 变化幅度为2.52%。同时 >0.25 mm粒级团聚体含量占整个团聚体的60%, 对有机碳含量的提高起主要作用。Hu占土壤有机碳50%以上, 土壤有机碳的变化必然会反应在Hu数量或结构上。

由表3可见, 用此方法制备的Hu的含碳量平均值为 721 g kg^{-1} , 较相应的HA(583 g kg^{-1})高; H/C平均值为0.776, 较相应的HA(1.07)低; $(\text{O}+\text{S})/\text{C}$ 平均值为0.222, 较相应的HA(0.41)低。说明Hu的分子缩合度和复杂程度较高, 氧化度较低。

由表3还可以看出, 不同粒级之间或不同土层间, 土壤团聚体中Hu的H/C和 $(\text{O}+\text{S})/\text{C}$ 均没有显著差异。但是经过秸秆深还, 不同处理之间差异显著: 就各粒级团聚体中Hu的平均含碳量而言, CK表层和亚表层分别为 739 g kg^{-1} 和 625 g kg^{-1} , DAS分别为 789 g kg^{-1} 和 728 g kg^{-1} , 升高幅度分

表3 秸秆深还对土壤团聚体中Hu的元素组成的影响

Table 3 Effects of DAS on elemental composition of HA in soil aggregates

采集深度 Depth (cm)	处理 Treatment	粒级 Fraction of particle size (mm)	C (g kg ⁻¹)	H (g kg ⁻¹)	N (g kg ⁻¹)	O+S (g kg ⁻¹)	C/N	(O+S) /C	H/C
0 ~ 20	CK	> 2	730.0	44.01	29.35	196.6	0.0345	0.2020	0.7235
		2 ~ 0.25	737.7	47.38	30.11	184.8	0.0350	0.1879	0.7707
		0.25 ~ 0.053	758.4	44.52	31.07	166.0	0.0351	0.1642	0.7044
		< 0.053	731.1	44.67	28.62	195.6	0.0336	0.2006	0.7332
		$\bar{X}$	739.3	45.14	29.79	185.8	0.0345	0.1887	0.7329
	DAS	> 2	836.5	46.17	31.41	85.93	0.0322	0.0770	0.6623
		2 ~ 0.25	780.5	48.87	31.90	138.8	0.0350	0.1334	0.7515
		0.25 ~ 0.053	790.9	47.91	32.46	128.7	0.0352	0.1220	0.7268
		< 0.053	749.0	44.09	29.85	177.0	0.0342	0.1773	0.7064
		$\bar{X}$	789.2	46.76	31.40	132.6	0.0341	0.1274	0.7117
20 ~ 40	CK	> 2	542.2	43.30	24.77	389.7	0.0392	0.5390	0.9583
		2 ~ 0.25	637.8	43.77	31.45	286.9	0.0423	0.3374	0.8234
		0.25 ~ 0.053	640.3	48.61	28.70	282.4	0.0384	0.3308	0.9110
		< 0.053	680.6	46.90	33.40	239.1	0.0421	0.2636	0.8271
		$\bar{X}$	625.2	45.65	29.58	299.6	0.0405	0.3677	0.8800
	DAS	> 2	717.4	46.97	31.80	203.8	0.0380	0.2131	0.7857
		2 ~ 0.25	839.0	49.30	32.69	78.99	0.0334	0.0706	0.7051
		0.25 ~ 0.053	674.8	46.31	33.00	245.9	0.0419	0.2733	0.8236
		< 0.053	681.1	45.77	32.88	240.3	0.0414	0.2646	0.8064
		$\bar{X}$	728.1	47.09	32.59	192.3	0.0387	0.2054	0.7802

注：CK为未秸秆深还，DAS为秸秆深还； $\bar{X}$ 为四个粒级的平均值。下同Note: CK represents no-straw applied, DAS represents deep application of straw, $\bar{X}$ represents the average of four fractions of aggregates. The same below

别为6.53%和15.20%；表层和亚表层平均含氮量CK分别为29.8 g kg⁻¹和29.6 g kg⁻¹，DAS分别为31.4 g kg⁻¹和32.6 g kg⁻¹，升高幅度分别为5.28%和9.70%。说明秸秆深还促使Hu的碳、氮含量升高，且亚表层变化幅度大于表层，与SOC变化规律一致。Narendra和Rattan^[33]在施用麦秸试验中，土壤碳、氮含量也发生类似变化。

CK表层和亚表层（O+S）/C平均值分别为0.189和0.368，DAS分别为0.127和0.205，降低幅度分别为38.8%和56.6%，说明秸秆深还促使Hu的氧化度降低。新形成的Hu含有较多的甲氧基和较

少的羧基，随着腐解进行，甲氧基逐渐减少，羧基不断增加，Hu氧化度升高。而本试验结果可能是由于添加秸秆形成了较多新的Hu，新Hu的氧化度较低。对于秸秆深还使Hu氧化度降低的具体原因还有待于进一步的研究。

2.2 秸秆深还对土壤团聚体中Hu脂族和芳香结构比例的影响

经过秸秆深还，土壤团聚体中Hu的红外光谱（FTIR）如图1所示，图谱形状基本相同，但在以下四个区域存在不同程度的差异：2 920 cm⁻¹（不对称脂族C-H伸缩振动）、2 850 cm⁻¹（-CH₂-对称脂

族C-H伸缩振动)、 1720 cm^{-1} (羧基的C=O伸缩振动)、 1620 cm^{-1} (芳香C=C伸缩振动)^[34]。

主要吸收峰的相对强度(%)如表4所示。经过秸秆深还,不同处理间存在显著差异:就各粒级团聚体在 2850 cm^{-1} 平均值而言,CK表层和亚表层分别为10.4%和10.2%,DAS分别为7.91%和8.31%,降低幅度分别为27.1%和20.4%;就 1720 cm^{-1} 平均值而言,CK表层和亚表层分别为8.59%和8.24%,DAS分别为7.97%和7.62%,降低幅度分别为7.36%和7.92%。以上说明秸秆深还促使表层和

亚表层的脂族链烃和羧基碳均降低,这与元素中氧化度降低一致。侯淑艳^[8]研究表明,玉米秸秆促使土壤的铁结合胡敏素(HMi)脂族链烃含量减少、氧化度降低,与本研究结果基本一致。但彭义等^[35]认为秸秆覆盖有利于有机碳在表层的累积,显著增加芳香碳、脂肪碳及烷基碳含量。本试验结果可能是因为添加秸秆促使总生物量^[36]和微生物代谢速率^[37]提高,微生物促使Hu分子结构简单化^[27],从而Hu氧化度降低。

秸秆深还对土壤团聚体中Hu热稳定性的影响

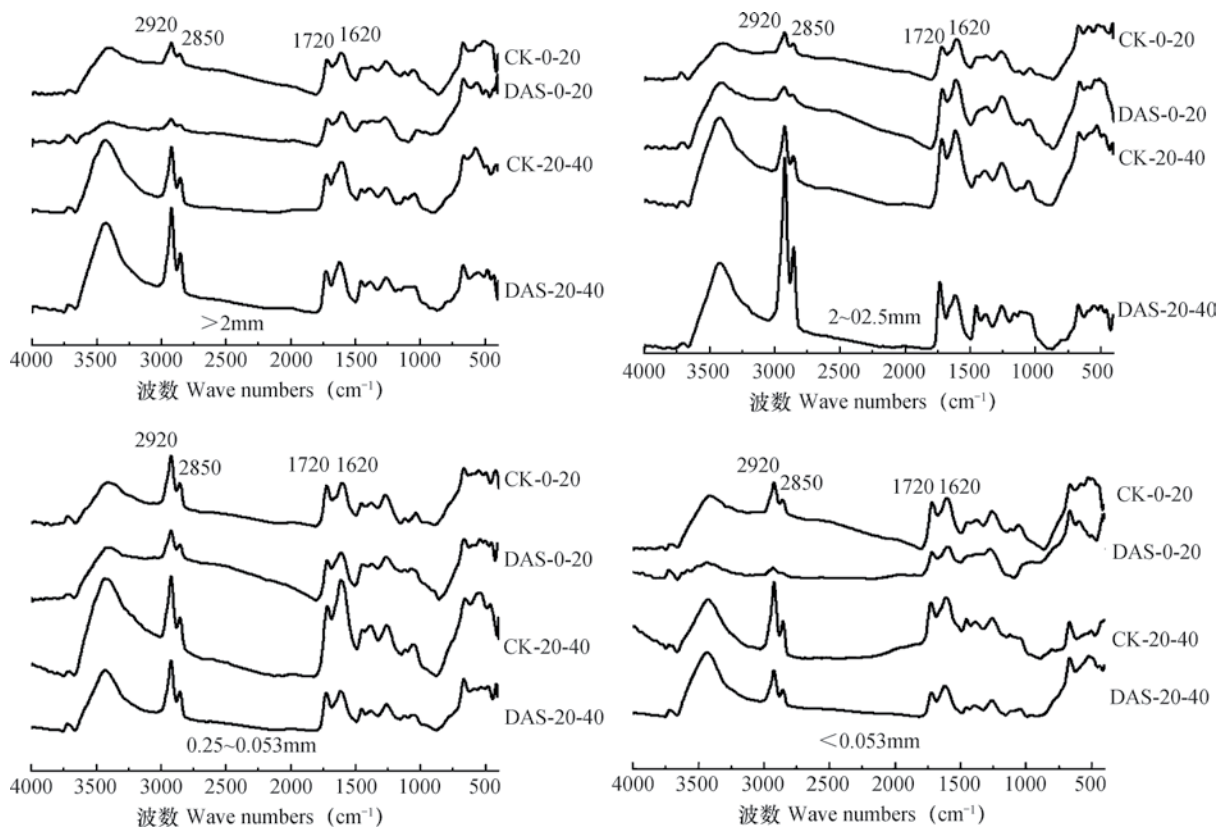


图1 秸秆深还对土壤团聚体中Hu的FTIR特征吸收峰的影响

Fig.1 Effects of DAS on FTIR spectra of Hu in soil aggregates

本试验针对土壤表层Hu进行了差热分析。各粒级团聚体中Hu的差热分析(DTA)均存在中温和高温放热峰(图2),中温放热峰温度范围为 $211\sim 324\text{ }^{\circ}\text{C}$,高温放热峰峰温范围为 $454\sim 466\text{ }^{\circ}\text{C}$ 。中温放热主要体现的是腐殖物质分子中外围官能团的脱羧反应和脂族化合物的分解,高温放热主要体现了腐殖物质分子内部芳香化合物分解和完全氧化的反应。

经过秸秆深还,土壤团聚体中Hu的热稳定性发生了显著变化(表5)。DAS各粒级的中温放热

峰峰温均低于CK; $>2\text{ mm}$ 、 $0.25\sim 0.053\text{ mm}$ 和 $<0.053\text{ mm}$ 粒级的高温放热峰峰温均高于CK;CK中温放热量的平均值为 1.08 kJ g^{-1} ,DAS为 1.31 kJ g^{-1} ,升高幅度为19.0%;CK高温放热量的平均值为 6.03 kJ g^{-1} ,DAS为 5.36 kJ g^{-1} ,降低幅度为11.8%;高温放热量减少、中温放热量增多,放热高/中必然会降低,CK平均值为 5.70 kJ g^{-1} ,DAS为 4.16 kJ g^{-1} ,降低幅度为31.2%。以上说明秸秆深还使得表层Hu的活性结构增多,惰性结构减少,稳定性降低,Hu结构趋于年轻化。崔婷婷^[23]认为

表4 秸秆深还对土壤团聚体中Hu FTIR光谱主要吸收峰相对强度的影响

Table 4 Effects of DAS on relative intensity of the main absorption peaks of FTIR spectra of Hu in soil aggregates									
采集深度 Depth (cm)	处理 Treatment	粒级 Fraction of particle size (mm)	相对强度 Relative intensity (%)				比值Ratio		
			2 920 cm ⁻¹	2 850 cm ⁻¹	1 720 cm ⁻¹	1 620 cm ⁻¹	2 920/1 720	2 920/1 620	2920/2850
0 ~ 20	CK	> 2	15.30	11.36	9.938	4.681	1.539	3.268	1.347
		2 ~ 0.25	8.173	6.076	6.186	7.873	1.321	1.038	1.345
		0.25 ~ 0.053	11.27	17.33	11.39	7.860	0.990	1.434	0.650
		< 0.053	9.345	6.808	6.871	7.963	1.360	1.174	1.373
		$\bar{X}$	11.02	10.39	8.595	7.094	1.303	1.728	1.179
	DAS	> 2	12.60	7.984	6.338	6.360	1.988	1.981	1.578
		2 ~ 0.25	7.556	6.581	7.170	8.424	1.054	0.897	1.148
		0.25 ~ 0.053	8.536	7.356	7.373	5.428	1.158	1.573	1.160
		< 0.053	10.91	9.723	11.03	11.35	0.989	0.961	1.122
		$\bar{X}$	9.899	7.911	7.977	7.890	1.297	1.353	1.252
20 ~ 40	CK	> 2	8.971	4.300	7.549	9.837	1.188	0.912	2.086
		2 ~ 0.25	14.60	12.96	8.565	9.621	1.705	1.517	1.127
		0.25 ~ 0.053	13.88	10.27	8.494	10.36	1.634	1.340	1.351
		< 0.053	19.99	13.29	8.382	7.613	2.385	2.625	1.504
		$\bar{X}$	14.36	10.20	8.248	9.357	1.728	1.599	1.517
	DAS	> 2	15.95	8.589	6.949	8.684	2.296	1.837	1.857
		2 ~ 0.25	19.56	9.756	7.901	6.806	2.475	2.873	2.005
		0.25 ~ 0.053	8.919	3.648	7.823	8.545	1.140	1.044	2.445
		< 0.053	15.30	11.26	7.805	8.865	1.960	1.725	1.358
		$\bar{X}$	14.93	8.314	7.620	8.225	1.968	1.870	1.916

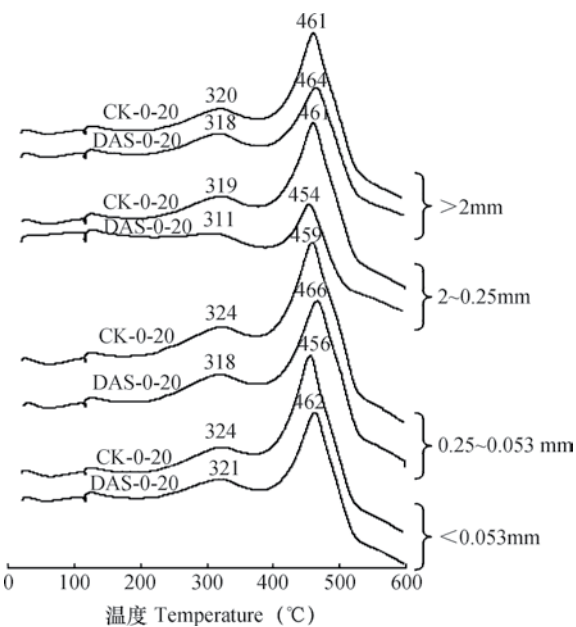


图2 秸秆深还对土壤团聚体中Hu的差热分析的影响
Fig. 2 Effects of DAS on DTA of Hu in soil aggregates

秸秆深还使Hu的缩合程度降低，这与本试验结果一致。崔凤娟等^[38]认为免耕秸秆覆盖处理显著提高土壤总有机碳、可溶性碳、微生物生物量碳及易氧化碳的含量，秸秆中纤维素含有较多的脂族结构和易氧化碳，这些活性结构进入土壤中影响Hu，对Hu稳定性较低有积极的影响。

3 结 论

通过对黑土秸秆深还后土壤表层和亚表层团聚体中胡敏素（Hu）结构特征的研究，得出以下结论：（1）用此方法制备的Hu的含碳量比较高，在542 ~ 839 g kg⁻¹范围内，平均值为721 g kg⁻¹；H/C在0.662 ~ 0.958范围内，平均值为0.776。说明Hu的缩合度高于相应的HA。（2）秸秆深还促使土壤表层和亚表层团聚体中Hu的氧化度降低，脂族链

表5 秸秆深还对土壤团聚体中Hu在差热分析中放热的影响

Table 5 Effects of DAS on exothermic heat of Hu in soil aggregates in differential thermal analysis					
采集深度 Depth (cm)	处理 Treatment	粒级 Fraction of particle size (mm)	放热量		热量高/中比值 Exothermic heat ratio of moderate and high temperature
			Exothermic heat (kJ g ⁻¹)		
			中温 Moderate temperature	高温 High temperature	
0 ~ 20	CK	> 2	1.270	6.540	5.150
		2 ~ 0.25	1.170	5.840	4.991
		0.25 ~ 0.053	1.030	5.570	5.408
		< 0.053	0.851	6.160	7.241
		$\bar{X}$	1.080	6.028	5.697
	DAS	> 2	1.430	4.820	3.371
		2 ~ 0.25	1.420	5.110	3.599
		0.25 ~ 0.053	1.170	5.900	5.043
		< 0.053	1.210	5.590	4.620
		$\bar{X}$	1.308	5.355	4.158

烩减少，活性结构增多，稳定性降低，Hu的结构趋于简单化、年轻化。

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Effect of deep application of straw on composition of humin in soil aggregates

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Abstract How to handle surplus crop straw has become an important topic that calls for urgent solution in the agricultural regions of China. Straw incorporation into the field is one of the main methods of straw utilization. The method of straw incorporation used to either overcast the straw on the surface of the field like mulching or incorporate the straw into the shallow topsoil layer, which would obviously bring about some problems, like hindering seed germination and seedling growth, impeding rise of soil temperature, and favoring incidence of plant diseases and insect pests, while its effect on accumulation of soil organic matter is so limited that it would not help solve the problems, like thinning of the plough layer and depleting of organic matter in the subsoil layer. Deep application of straw (DAS) extends the extent of soil building from topsoil, as it was previously, down to subsoil, which would not only help solve problems, like thinning of the plow layer, shortage of organic manure, declining water holding capacity, but also reduce environmental pollution from burning of straw, while achieving the ends of sequestering carbon, conserving soil water, building up soil fertility and raising crop yield. Although some reports are available on change in structure of Hu after DAS, few have been published on Hu in soil aggregates.

Soil samples were collected from an experimental corn field under long-term mono-cropping in the Jilin Agricultural University Experiment Station. The experiment field of black soil was divided into two plots, one cultivated under DAS and the other without DAS (CK). In the plot under DAS, ditches were dug along the furrow in-between two rows of corn plants in November 2011, with a section like a bottom-up isosceles trapezoid, 60 cm wide in the upper opening, 40 cm wide in the bottom and 40cm in depth. In the process of digging, the soils of the top layer (0 ~ 20 cm) and the sublayer (20 ~ 40 cm) were dug out layer by layer and placed separately on either side of the ditch. Once a ditch was dug into shape, corn stalks, cut into 3 ~ 5 cm in length were applied into the deep ditch evenly at a rate of 12 000 kg hm⁻², together with N fertilizer (urea 450 kg hm⁻²), and then the removed soil was placed back into the ditch, the sublayer soil first and then the top layer soil forming a big ridge, which was let subside naturally. After the practice of DAS finished, the two plots were cultivated with corn in the same pattern. At the end of the cropping season, soil samples from the topsoil and subsoil layers of the two plots were collected and screened separately into four fractions of soil aggregates, > 2mm, 2 ~ 0.25 mm, 0.25 ~ 0.053 mm and < 0.053 mm with the wet sieve method. Hu was extracted with the HCl-HF extraction method from each fraction of soil aggregates, and analyzed for element composition and structural features with the infrared spectroscopy and differential thermal method. Comparison was performed to determine effects of DAS on Hu structural feature. The findings of the study may provide some theoretical basis for how to improve soil fertility and build up a proper plow layer with DAS.

Results show that the Hu in the plot of DAS is higher in carbon content, varying in the range of 542 ~ 839 g kg⁻¹ and averaging 721 g kg⁻¹, with H/C in the range of 0.662 ~ 0.958, and being 0.776 in average, and higher than HA in carbon content and condensation degree. DAS was found to increase carbon and nitrogen contents, and reduce Hu oxidation and aliphatic hydrocarbon degrees. The effects are more significant in the sublayer soil than in the top layer soil. Besides, DAS increases active structure of the Hu, but lowers

its stability, To sum up, DAS increases carbon and nitrogen contents in Hu, while making it simpler and younger in structure.

Key words Deep application of straw; Soil aggregate; Humin; Element composition; Infrared spectroscopy; Differential thermal analysis

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